Detectors For Synchrotron Research

Berkeley Lab

High Event Rate 2D Detectors

Jacques Millaud*, Pier Franco Manfredi**, Philip Datte,
Jean Francois Beche and Vitali Souchkov

LAWRENCE BERKELEY NATIONAL LABORATORY
Engineering Division
Engineering Science Department
Measurement Science Group

* Contact JEMillaud@lbl.gov, Tel: (510) 486 4169
** Also with the University of Pavia (Italy)

Detectors For Synchrotron Research

Topics to be Addressed:

* 2D Detectors: Information Content and Readout Methods.

* Examples of Current Developments at LBNL:
  1- Protein Crystallography.
  2- 2D Interpolative Readout of Micro Channel Plates.
  3- Germanium/Spectrometric Applications.

* System Issues with 2D Pixel Array Detectors.

* Developments needed for high Event Rate Detectors.

Detectors For Synchrotron Research

Detectors Classification By:

- Type of Information
- Mode of Acquisition

Detectors For Synchrotron Research

Type of Information

Event Driven*

Frame

Based | Independent

Readout

Sequential Or Concurrent | Concurrent

* Signals from photons and particles are processed individually.

Detectors For Synchrotron Research

Type of Information

Energy Deposited Over a Period of Time

CCDs

Photodiode Arrays

Hybrid Pixels

Sequential Readout of Frame

Detectors For Synchrotron Research

Mode of Acquisition

Frame Based

- Event Driven
  - Counting
- Integrated Energy

Detectors For Synchrotron Research

Mode of Acquisition

Frame Independent

Concurrent Acquisition and Readout

Event Driven

- Counting
- Multiparametric

Deposited Energy Integrating Devices

- Fast acquisition feasible with gated systems.
- Readout speed decreases with increasing accuracy.
- Subject to limitations of analog data capture:
  - * Noise (detector dark current, electronic...).
  - * Non linearities.
  - * Gain dispersion across channels.
  - * Electronics, detector and physics cross talk.
- Essentially all pixels must be readout and/or reset during readout.

Event Driven Systems

- Signals created by individual photons or particles are processed on a per event basis. Signal amplitude discrimination is used to define the occurrence of an event.
- This processing is slower than for integrating devices. The event rate depends on:
    - * The signal to noise ratio of the events.
    - * The time response of the detector.
    - * The speed of the signal processing function.
    - * The overall bandwidth of the readout architecture.

Event Driven Systems

- Photon/Particle counting will generally be faster than acquiring and reading out multi-parametric data.
- An event can be a collection of primary events I.e. counting systems with pre-scaling.
- Event driven systems are usually not very sensitive to "analog effects".
- Counting losses can be estimated hence to a certain extent it is possible to operate at higher rates with known losses.

Frame Based Readout

- The entire detector must be readout/reset although for some applications only a subset is needed.
- Each pixel contains storage for at least one frame. Multi-frame storage is feasible when the number of frames is small.
- No system clocks are in operation when readout is not concurrent with acquisition.
- This is not the case when acquisition and readout are concurrent. Furthermore a dedicated readout frame is needed.

Event Based Readout/Frame Independent Operation

- Within the limitations of the servicing of the event queue,the readout logic reads events as they occur. This is the only feasible approach for multi-parametric events.
- This approach matches quite well the requirements of the study of time resolved processes.
- Event readout rate is dependent on the complexity of the event data and on the parallelism of the readout architecture.

The Column Architecture

- A fast, massively parallel architecture. Columns (or columns subsets) operate as independent linear arrays of pixels. 2D systems are effectively reduced to 1D.
- No system level clocking.
- Sparse readout: Only requesting events are readout.
- No addressing ambiguity thanks to the reduction from 2D to 1D.
- Concurrent acquisition and readout: Frame independent, essentially without dead time and seamless behavior at high event rate on the detector due to low column rate and readout simplicity.

The Column Architecture (Cont.)

- Unbounded dynamic range, no frame storage hence no frame saturation.
- Low dynamic power dissipation as events are distributed over the detector and only local logic is involved in the event readout and registration.
- ASICs can be tiled on 3 sides with minimum dead space.
- Increased system reliability. The failure of a column does not impair the operation of the entire array.

Detectors For Synchrotron Research

Topics to be Addressed:

* 2D Detectors: Information Content and Readout Methods.

* Examples of Current Developments at LBNL:

    1- Protein Crystallography.

    2- 2D Interpolative Readout of Micro Channel Plates.

    3- Germanium/Spectrometric Applications.

* System Issues with 2D Pixel Array Detectors.

* Developments needed for high Event Rate Detectors.

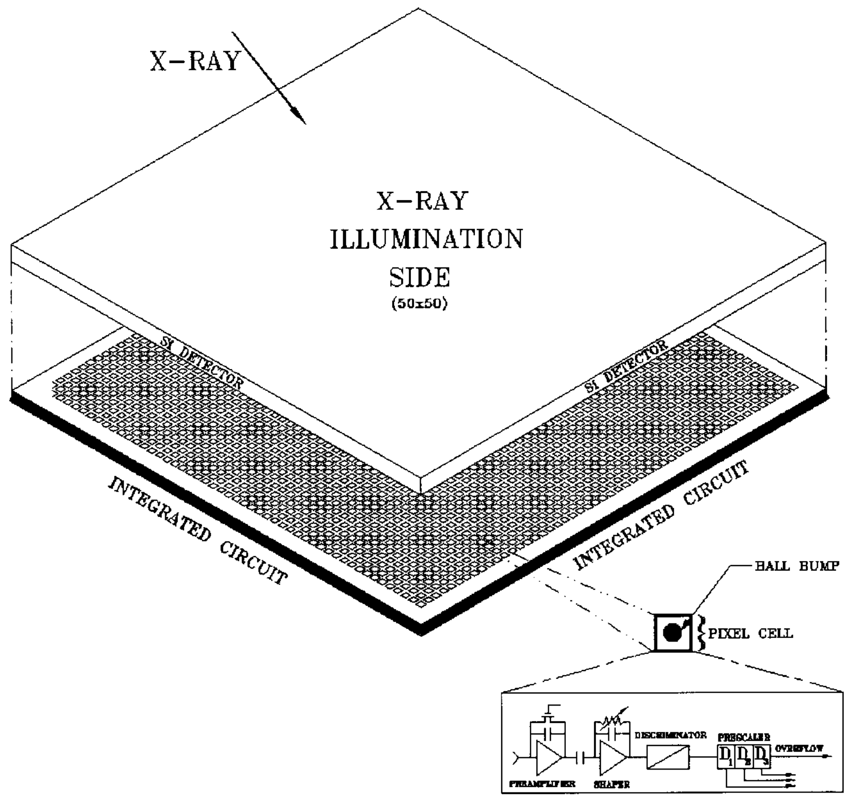
A Detector For Protein Crystallography

- Column Architecture.
- Event: Overflow of a pixel's 3 bit pre-scaler (8 photons).
- Maximum counting rate: 10^6 phs/pixel/s (125,000 events).
- Average counting rate: 10^5 phs/pixel/s (12,500 events).
- Using 150x150 um pixels: $0.44 10^9$phs/cm^2/s or 10^{11} phs/s for a 15x15 cm^2 detector area.
- Event readout time: 80ns.
- Average occupancy of the readout: 5% (50 pixels column).

A Detector For Protein Crystallography

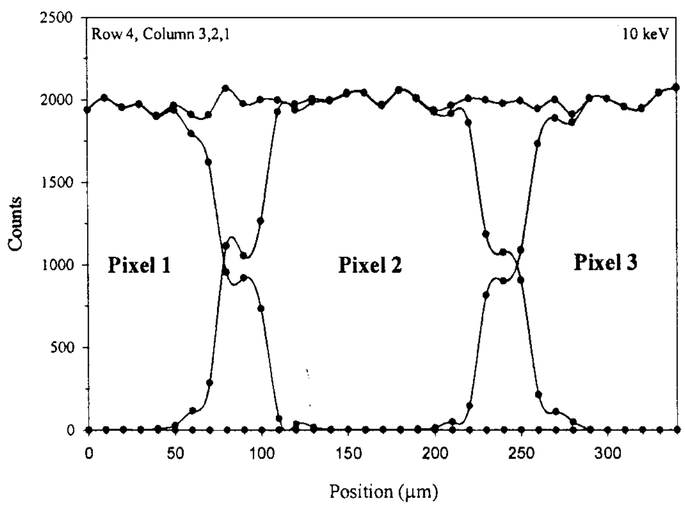
- Detector background rate at 800 electrons discriminator threshold: < 1 event/1000s.
- Pre-scalers content readout time: ~15 us.
- Programmable test/calibration bit and enable/disable bit per pixel for functional, parametric and pattern sensitivity tests.
- Adjustable chip level discriminator thresholds.
- Future developments target pixel size reduction to 100x100um at same rate/pixel, and the acceleration of the readout time of the pre-scalers.

Detectors For Synchrotron Research



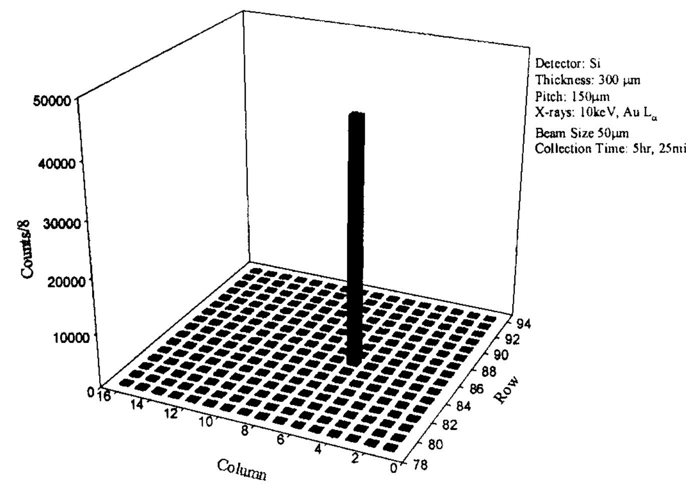
Detectors For Synchrotron Research

Si PIXEL DETECTOR
8x8 ARRAY
150 µm PITCH
DISCRIMINATOR 80 mV



Si Detector 300 (µm)
Bias Voltage 80 Volts
Pixel Pitch 150 (µm)
Beam Size 35 (µm) 5mm from detector
Discriminator 80 mV
Pixel Row 4
Collection Time 240 sec
Energy 10 keV

16x16 Si Digital Pixel Array Detector

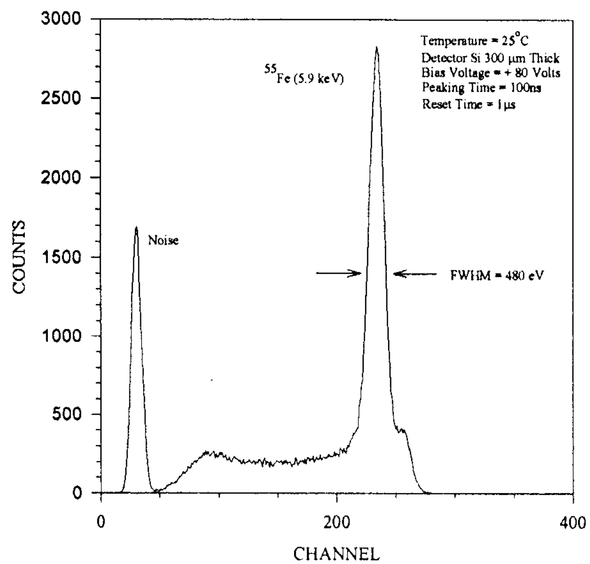


7	2	0	2	4
11	8	6	0	6
4	27	51	10	4
13	127	44529	27	6
11	20	37	15	4
6	4	4	3	3
4	1	6	1	4

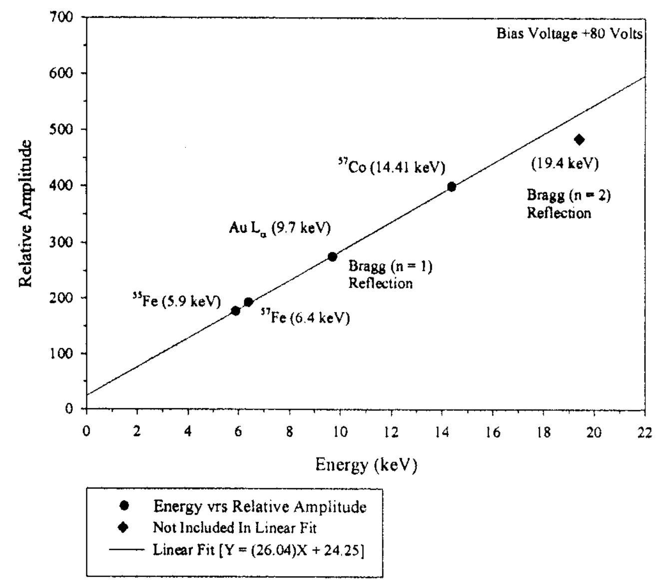
DIGITAL PERFORMANCE

Detectors For Synchrotron Research

Si Pixel Detector
8x8 Array
150 μm Pitch - Thickness 300 μm

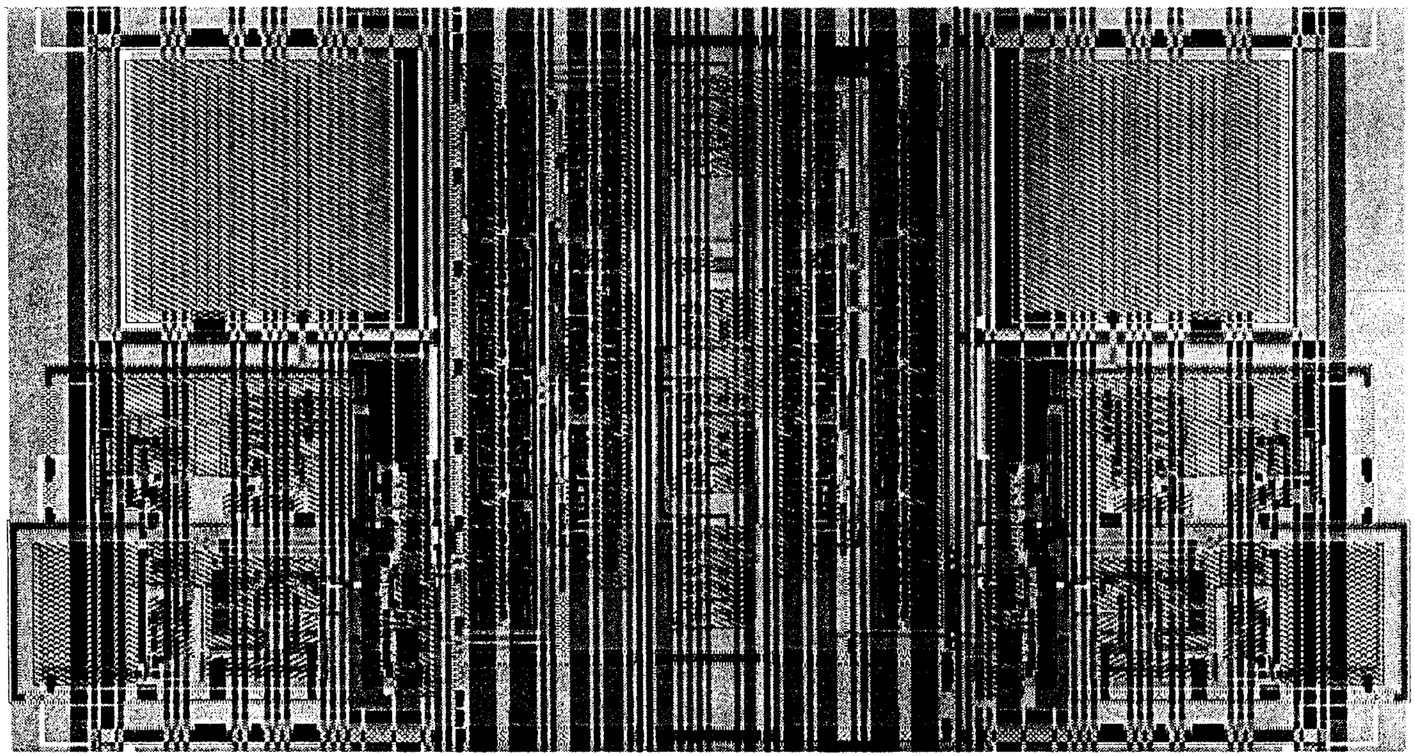


Si Pixel Detector
Linear Energy Plot
150 μm Pitch
Pixel (4-4)



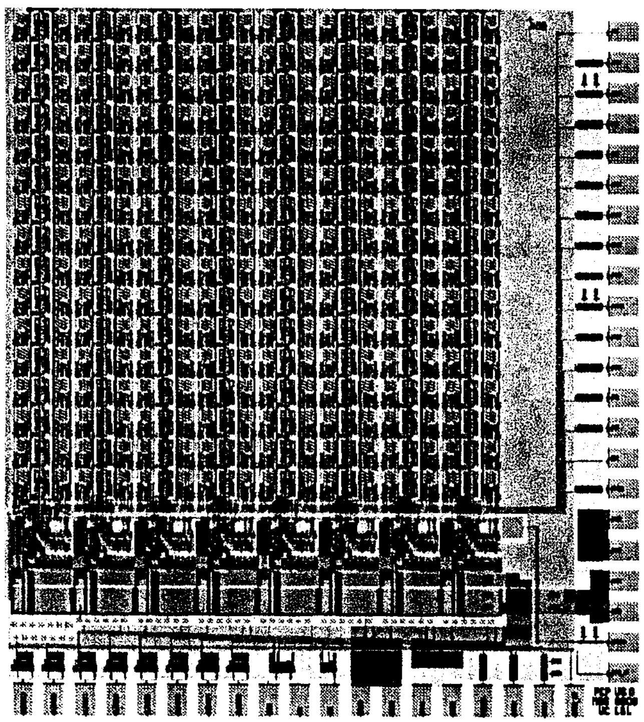
ANALOG PERFORMANCE

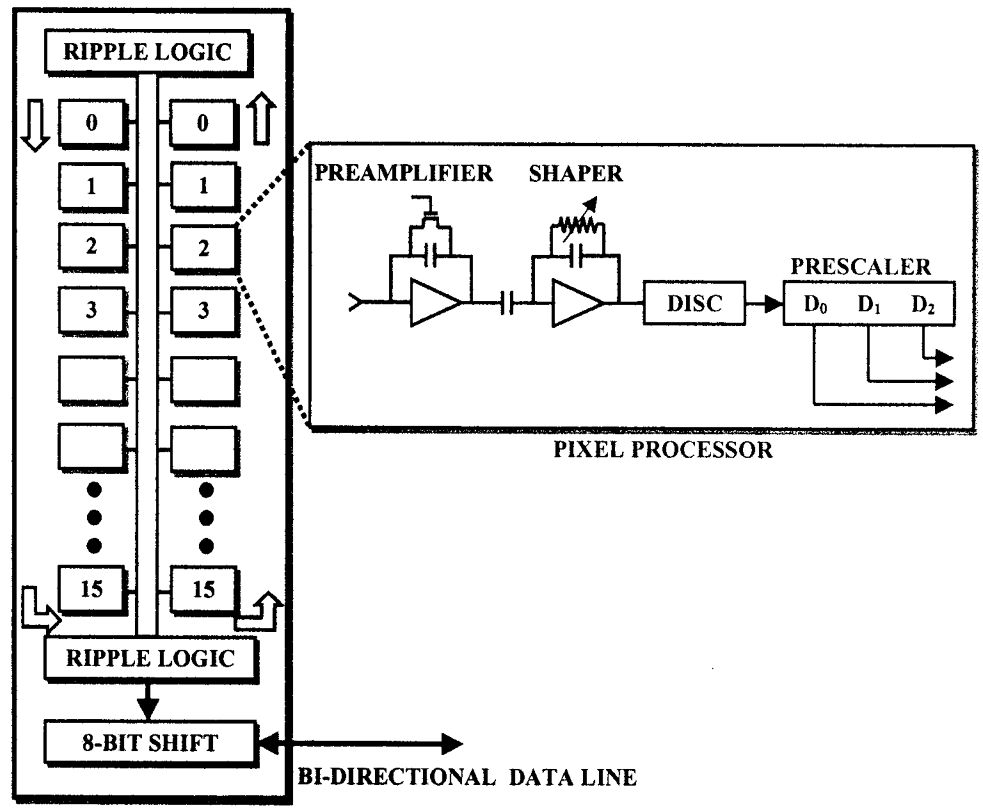
Detectors For Synchrotron Research



LEFT & RIGHT PIXEL OF A DUAL COLUMN

Detectors For Synchrotron Research



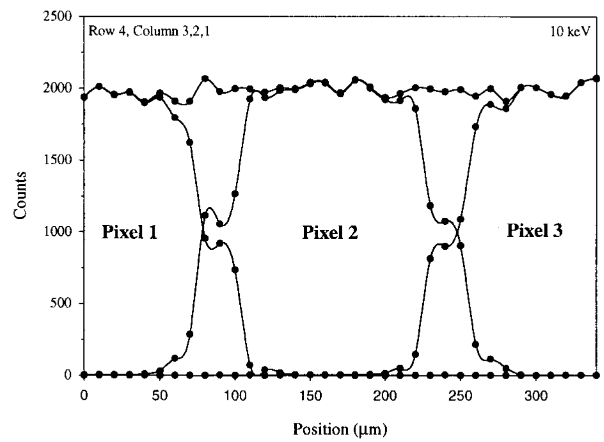


16 X 16 ASIC

COLUMN LOGIC

Detectors For Synchrotron Research

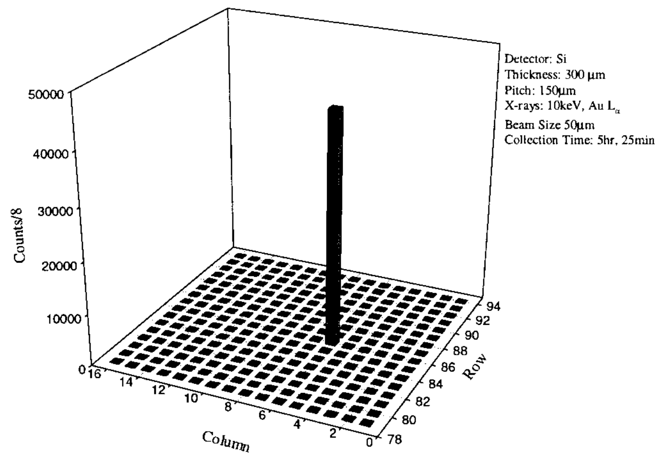
Si PIXEL DETECTOR
8x8 ARRAY
150 μm PITCH
DISCRIMINATOR 80 mV



Si Detector 300 (μm)
Bias Voltage 80 Volts
Pixel Pitch 150 (μm)
Beam Size 35 (μm) 5mm from detector
Discriminator 80 mV
Pixel Row 4
Collection Time 240 sec
Energy 10 keV

Detectors For Synchrotron Research

16x16 Si Digital Pixel Array Detector



7	2	0	2	4
11	8	6	0	6
4	27	51	10	4
13	127	44529	27	6
11	20	37	15	4
6	4	4	3	3
4	1	6	1	4

Detectors For Synchrotron Research

BERKELEY LAB

Topics to be Addressed:

* 2D Detectors: Information Content and Readout Methods.

* Examples of Current Developments at LBNL:
    1- Protein Crystallography.
    2- 2D Interpolative Readout of Micro Channel Plates.
    3- Germanium/Spectrometric Applications.

* System Issues with 2D Pixel Array Detectors.

* Developments needed for high Event Rate Detectors.

Detectors For Synchrotron Research

2D High Spatial Resolution Readout of Micro Channel Plates

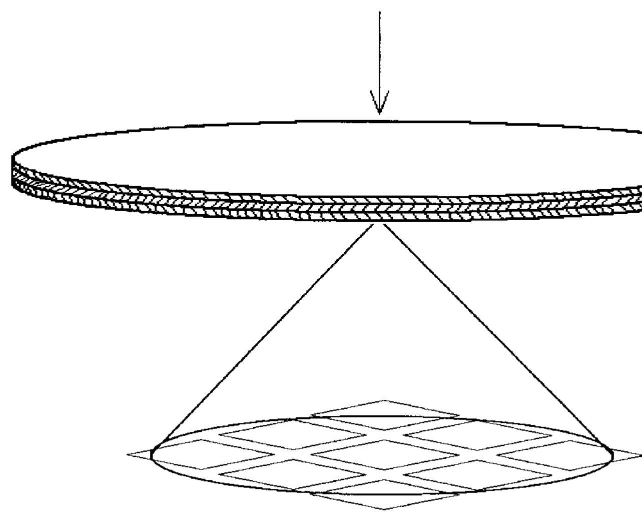


Figure 1.

- Event is information (photon/particle) + cluster recognition + (options: Time...)

2D High Spatial Resolution Readout of Micro Channel Plates

Why MCPs?

- Can be used to detect from IR to UV, low energy X-rays, electrons, neutrals…
- High event rate, high spatial resolution applications.

OR

- High spatial resolution, high time resolution (<0.5ns) and low event rate in applications such as photo-dissociation.

2D High Spatial Resolution Readout of Micro Channel Plates

- Current state of the art:

  Event rates of less than 1 MHz over a 4x4cm^2 area using a 2D projective approach on delay lines. Spatial resolution better than <20um. Recently O. Siegmund (SSL) has indicated 5um using projective strips.
- Targets: 1) Within 2 years 10MHz/cm^2 @25um spatial resolution using pixilated collectors. 2) Within 3-4 years 100MHz/cm^2 @25um.
- Developments needed: Interpolators, architectures, circuits.

Detectors For Synchrotron Research

Topics to be Addressed:

* 2D Detectors: Information Content and Readout Methods.

* Examples of Current Developments at LBNL:
    1- Protein Crystallography.
    2- 2D Interpolative Readout of Micro Channel Plates.
    3- Germanium/Spectrometric Applications.

* System Issues with 2D Pixel Array Detectors.

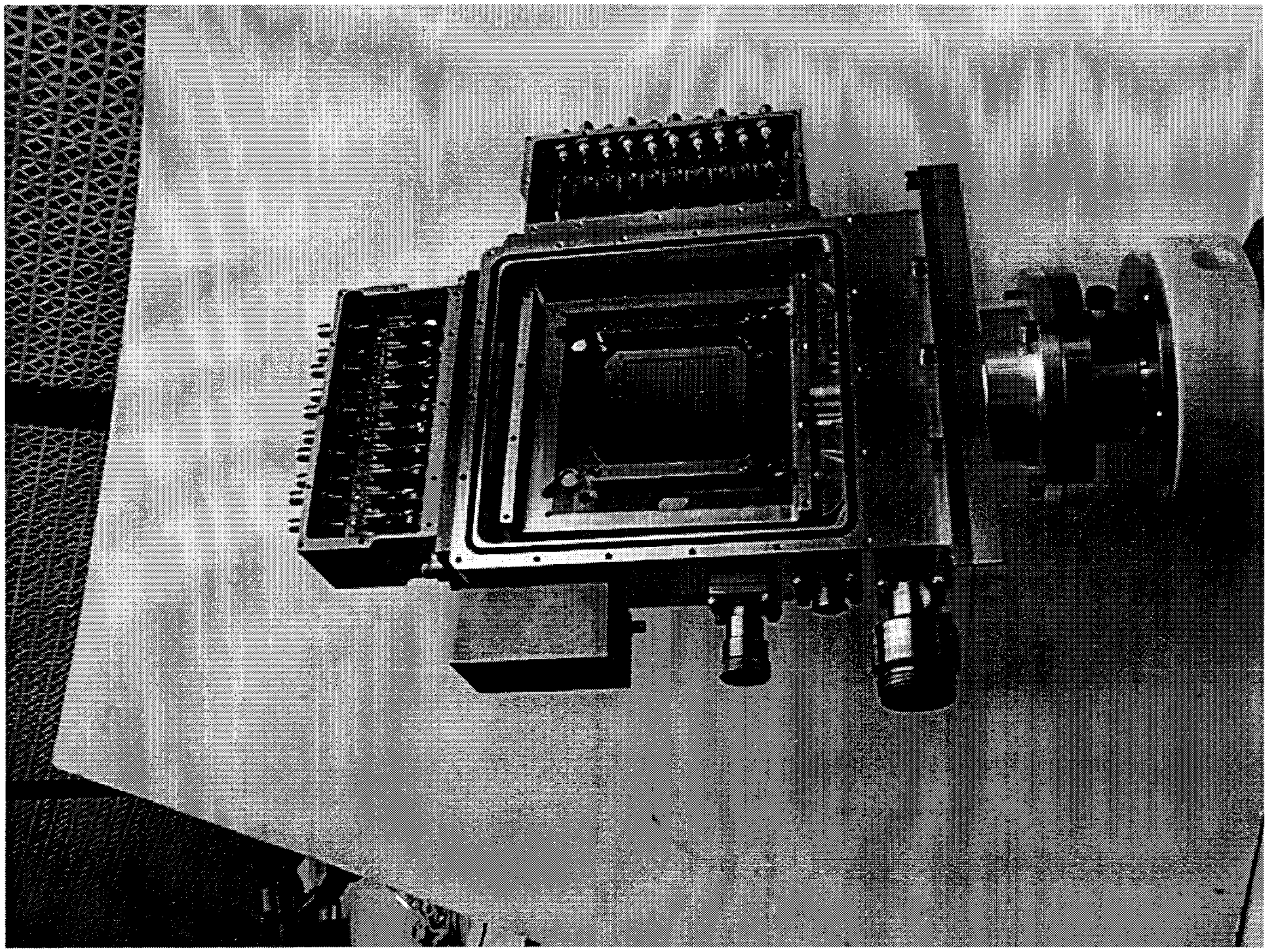
* Developments needed for high Event Rate Detectors.

Detectors For Synchrotron Research

High Energy Resolution Systems

- Multi-elements Germanium
- Energy Resolution of 275eV (Fe^{55}) @ 250ns peaking time.
- Event rate/pixel ~ 1 Mhz.
- Pulse processing electronics: no dead time after pre-amp, 150ns, 12bit nuclear quality ADCs.
- 2D detectors using cross strips.
- 2mm pitch strips, spatial resolution better than 2mm.
- Mechanically cooled detectors.

Detectors For Synchrotron Research



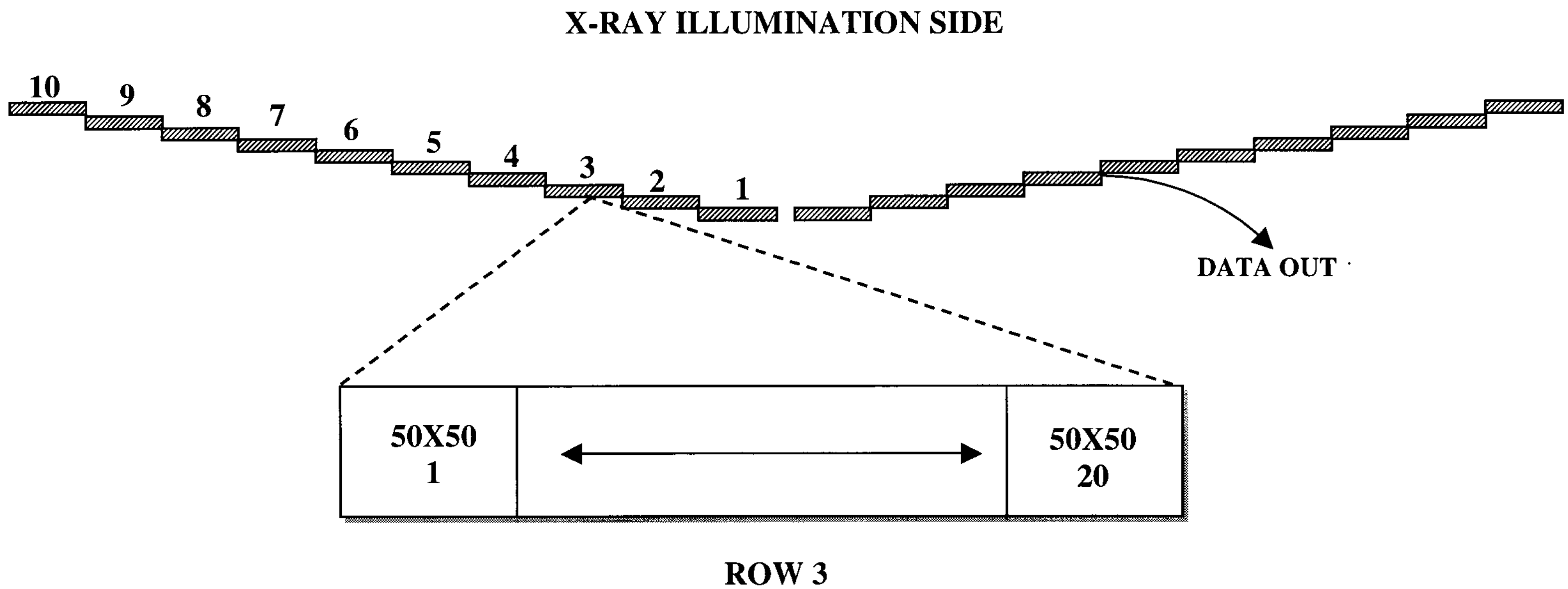
System Issues: Hybridization

- Flip Chip technology using solder, gold or indium bumps with or without an interposer.
- Silicon detectors: no specific problems although extra noise has been reported when indium was used.
- MCPs: Higher density of bumps at the ASIC periphery in order to route information that must be shared.
- Germanium: This is a technology that must be developed.

System Issues: Detection Plane

- Gaps will exist between detectors/ASICs assemblies. These gaps originate both in the detector (guard ring) and in the ASIC (data collection and routing to the computer). Detectors structures have been proposed that essentially eliminate the impact of the detector guard ring (S. Parker SLAC/LBNL).
- With advances in interconnection technology and interposers the impact of the gaps will be lessened but maps and correction factors will be needed.

Detectors For Synchrotron Research



System Issues: Radiation Hardness

- Silicon Detector: No damage to crystal. Trapping may occur.
- ASICs: @10^6phs/pixel/s and 10% transmitted to the ASIC there is only a fraction of a Rad/pixel/s.

  Options: Use a Rad-hard process and design for radiation hardness OR use an x-ray absorbing interposer.
- MCPs: There are no issues at the ASIC level as ~2 KeV electrons will be absorbed in the collecting electrodes and their substrate.

BERKELEY LAB

Other System Issues

- Power dissipation is of the order of 250uW/pixel. Heat removal is sufficient for event driven pixels. Integrating devices may require cooling to reduce the dark current.
- Test and Characterization:

  * Functional testing.

  * Parametric testing.

  * Pattern sensitivity testing.
- Flexibility of operation: Programmability of thresholds and masks.

Detectors For Synchrotron Research

Developments Needed for High Event Rate Detector

- Multiparametric Detectors:
  * Architectures capable of supporting higher rates.
  * More accurate, faster and simpler interpolators and digitizers.
  * Simpler and smaller circuits.
- Improvements in interconnection technology and interposers/absorbers.
- Smaller pixels (100x100um).
- Germanium: Electronics and interconnection operating at the liquid nitrogen temperature. Higher cooling power mechanical coolers.